Hydrological Memorandum No. 43

Revised monthly and annual totals of rainfall representative of Kew, Surrey for 1697-1870 and an updated analysis for 1697-1976

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by

B.G. Wales-Smith

MetO 8 (Hydrometeorological Services)
March 1980

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REVISED MONTHLY AND ANNUAL TOTALS OF RAINFALL REPRESENTATIVE OF KEW, SURREY FOR 1697–1870 AND AN UPDATED ANALYSIS FOR 1697–1976.

By B.G. Wales-Smith

SUMMARY

Monthly rainfall totals recorded at sites in or near the London area during the period 1697–1855 were examined and compared. Quality-control processes were carried out, taking account of known or deduced site peculiarities; these led to the rejection of certain records and to the compilation of a best estimate data series for each acceptable record. Estimates of monthly rainfalls for the site of Kew Observatory were made from the best estimates at other sites for the period 1697–1855. These estimates together with the modern Kew record which began in 1856 (known collectively as Kew 2) were subjected to simple analysis and the results compared with those obtained from an earlier assemblage known as Kew 1. It is shown that the revision of values used up to 1855 and the introduction of additional Kew data for 1856–70 makes important changes to the time series, but that a frequency analysis of Kew 1 gives similar results to those obtained from Kew 2.

1. INTRODUCTION

Since publication of the first assemblage of monthly rainfall totals representative of Kew, Surrey for the period 1697 to 1870 (Wales-Smith, 1971) a substantial amount of additional numerical data, together with details of gauges and sites, has come to light. The additional information has been used to develop a revised assemblage of monthly rainfall totals, known as Kew 2 (see Appendix); it includes data observed at Kew itself from 1856 onwards. Objective procedures have replaced subjective judgement wherever poss possible. The assemblage Kew 2 has already found application in a variety of studies.

2. DATA

The Summary, given in Wales-Smith (1971) listed only Britton (1925) and Brazell (1968) as sources of data for Kew 1 . Further work by Craddock (1976), by Professor Gordon Manley and by the author has added the following data:

1738–41	Chelmsford
1750–51	Caenwood, London (alternatively Kenwood or Caenwood Towers – perhaps near Hampstead Heath) – these data were examined after Kew 2 had been completed; they support the values adopted.
1774–79	Crane Court, London (The Royal Society)
1780	Somerset House, London (The Royal Society)
1782–83	Camberwell
1787–88	Gravesend
1797–1838	Sunbury-on-Thames
1797–1818, 1820	Tottenham
1802–06	(incomplete) Camden Town
1810–12, 1820	Stratford
1809–15	Highgate Hill

1826–70,
1873–78 Chiswick

1856–70 Kew Observatory.

There is also an earlier set of rainfall records from Kew covering the period 1774–1860, in addition to the good-quality record from 1856 to 1870, listed above. These very early data have been compared with contemporary data from Chiswick and from Sunbury-on-Thames (which agree very well with one another and equally well with the other Kew record which started in 1856). Sadly, the author has found no acceptable way of using these earliest known Kew data. Jacobs (1969) gives the following information – 'As, at this initial stage, the Observatory had no ground available on which to place instruments the rain-gauge was placed on a pole on the roof – it is clearly visible in the original of the 1792 print reproduced in Plate III and Ronalds confirms the position in a later report'.

3. GAUGE AND SITE DETAILS OF EARLY RECORDS

The following details were known to the author at the time of compiling 'Kew 2':

Upminster (Rev. William Derham, FRS) 12 inch diameter funnel. Craddock (1976) found a document in the Royal Society library in which Derham stated that he followed the rain-gauging methods of Richard Towneley (of Towneley, near Burnley). Towneley's gauge was 9 yards above a point near his study window and 10 above the ground (Folland and Wales-Smith, 1977). Towneley reported to the Royal Society that there was no obstruction near the gauge. A similar exposure has, therefore, been assumed for the Upminster gauge.

Crane Court, Fleet St, London (F. Hawksbee for The Royal Society). Twelve inch diameter gauge with rim 3 ft 6 in above a flat roof.

Falkham, Kent (John Hooker). No details (see Hooker's diary, Royal Society MS NA 188).

North Fleet, Kent (John Hooker). No details.

Tonbridge, Kent (John Hooker). In a letter to J.M. Craddock, Hoole (1976) stated that Hooker bought the largely ruined castle and the lordship of the manor in about 1730. He took up residence in Tonbridge and built, around 1760, a house which now forms part of Tonbridge School, a little to the north-east of the castle and some 90 ft above mean sea level. Manley (1960) had been unable to indicate the location of Hooker's three sites but Hoole's communication seems to locate at least the site of the last four or five years of the Tonbridge record and to imply that the whole record was made in the town itself.

Chelmsford (record published by Dr T. Short). No details.

Caenwood, London (the Earl of Bute). Professor Manley has discovered that the Earl kept records of rainfall at Mountstuart, near Rothesay, using a pitcher which appears to have been placed on the lawn; the catch of rain was measured with a metal container of known volume. Measurements of rainfall were also made at the Earl's Caenwood house, probably starting in the late1740s. Professor Manley has 're-constructed' this record as monthly and annual totals (in inches) for 1750 and 1751.

Lambeth ( ).* No details.

South Lambeth (Earker). No details.

Camberwell ( ). No details.

Gravesend (Charles Kite). Special pluviometer with 100-square-inch collector. The apparatus was housed in a wooden case close to the ground.

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* Empty parentheses signify 'observer unknown'.

Somerset House, Strand, London (The Royal Society). No details of the sizes of several gauges. One was attached to a chimney and in 1814 there were at least two gauges a few feet apart; one was 11 ft 6 in lower than the other. G.J. Symons stated (BAAS 1865) that one of these gauges was 150 ft above sea level.

Temple Bar, London ( ). No details.

Sunbury-on-Thames (Rev J. Cowe). Six inch diameter funnel. The gauge rim was 2 ft above ground in a garden, 38 ft above sea level.

Tottenham (Luke Howard). No details of the construction of the gauge have been found, but it was 43 ft above ground until July 1810 when it was transferred to 'ground level'. (Monthly and annual totals in the Meteorological Office archives, obtained from Howard's *Climate of London*, are annotated 'corrected for elevation of gauge').

Camden Town (J.J.). No details of construction of the gauge have been found but it was placed 17 feet above ground.

Stratford, Essex (J. Gibson). No details.

Highgate Hill, London (J.J). 10 inch diameter gauge, 6 ft above ground, near the top of the hill.

Soho Square, London (Sir J. Banks). No details of the construction of the gauge have been found but it was placed on a library roof.

Greenwich Observatory. Writing in 1873 (Brazell, 1968), G. Dines stated 'it seems to have been assumed that the old gauge was placed above the ground – whether it was or not, or at what height I suppose no-one can now tell'. It seems likely that he referred to the gauge in use during the period 1815–31 and perhaps later. G.J. Symons, (BAAS 1865), reported that there were various gauges at the Observatory and that one was 155 ft above sea level. Brazell (1968) suggests that a gauge was above ground level during the early years.

Chiswick (The Royal Horticultural Society). Five inch funnel with a collar to prevent rain running into the bottle from the outside of the funnel. By 1861 a 12 inch diameter gauge was in use; it was 3 ft 9 in above ground and 14 ft above sea level. During the period 1873–78 the gauge rim is stated to have been 9 in above ground and 25 ft above sea level.

Edmonton (C.H. Adams). No details of the gauge or site have been found but it is recorded that the gauge was 'blown down' in February 1811. This suggests that it was well above the ground, possibly on a wall or a roof.

Kew Observatory. G.J. Symons stated that the gauge used from 1856 was 19 ft above sea level and 10 in square, with the rim 1ft 3 in above ground. The site was 'In the Observatory enclosure but quite freely exposed. Ground (is) level for some distance, especially towards the Thames'.

4. DATA PROCESSING

4.1 Upminster 1697–1716

A reasonable value for the average annual rainfall in this area over the period 1941–70 is about 22.82 in (580 mm). The 1697–1716 average of annual totals is 19.99 in (508 mm) and the factor relating these averages is 1.14.

An early gauge some 30 ft above ground (see para. 3) would be likely to undercatch in relation to a good modern gauge in a good site. Results reported by Symons (1882) and by Mill (1901), confirmed by the use of Abbe's formula (Abbe, 1893) and by more recent experience suggest that Derham's gauge may have caught as little as 85 per cent of the rain falling on open, level ground. This would imply a factor of 1.18

to adjust the Upminster data to 'good modern standard'. The two factors (1.14 and 1.18) are in good agreement but it is probably not prudent to adjust the data to an average above the recent long-period value. The evidence upon which to make a decision is inadequate but to ensure no *under*-estimate all values have been multiplied by 1.14. In the derivation of Kew 1 no local adjustment was made to this record owing to lack of knowledge about the gauge and its probable site. Brooks (1926) considered that the Upminster gauge may have caught some 91 per cent of the catch of a conventionally exposed modern gauge.

4.2 Crane Court 1725–35 and 1774–79

During the period 1774–79, just before the Royal Society moved to Somerset House in 1780, the gauge was 3 ft 6 in above a flat section of the roof. The 1941–70 average annual rainfall value for the site of Crane Court is about 23.75 in (603 mm). The average of annual totals for 1725–35 is 21.74 in (552 mm) and the factor relating this to the modern average is 1.09. The 1774–79 average of annual totals is 24.12 in (613 mm), 101.6 per cent of the modern average. Craddock and Wales-Smith (1977) suggest that for the same period Pode Hole, near Spalding in Lincolnshire, had some 122 per cent of its 1941–70 average. If the average of the true falls at Crane Court for the period 1774–79 was as high a percentage of modern average as assessed for Pode Hole it would have been about 28.93 in (735 mm) or 1.2 times the modern average. Over the period 1726–35 Craddock and Wales-Smith suggest that Pode Hole annual values averaged about 97 per cent of the modern average. The 1726–35 average at Crane Court is 21.91 in (557 mm) which is 92 per cent of modern average. If, however, the falls at Crane Court over this period had been 97 per cent of modern average an adjustment factor of 1.05 would be required. Factors of 1.2, 1.09 and 1.05 have been obtained from what must be regarded as speculations based on what evidence is available. Bearing in mind that the measurements were made with a gauge of early design, 3 ft 6 in above a *flat* roof a factor of 1.1 was adopted for both periods of record. In Kew 1 the Crane Court data were accepted at face value for lack of convincing evidence to the contrary. The Librarian and staff of the Royal Society and J.M. Craddock have searched for rainfall records which may have been compiled for the Society during the period 1736–73 and 1781–86 but if these records ever existed they cannot now be found. The Society's rainfall record was terminated, by the Council, for scientific reasons, in 1843. Professor Manley has also sought evidence for the existence of the 'missing records' but without success.

4.3 The period 1717–24

This period is still not represented by any measurements of rainfall in or near the London area. As the (preceding) Upminster and the (following) Crane Court data have been adjusted upwards (Table 1 shows that for data derived from Upminster, Kew 2 = 1.09 Kew 1 and for data derived from Crane Court, Kew 2 = 1.11 Kew 1), the estimates made from George Smith's Richmond diary (Wales-Smith, 1971) have now been multiplied by 1.10 to give estimates for both Richmond and Kew.

TABLE 1 – MULTIPLYING FACTORS ADJUSTING KEW 1 ANNUAL TOTALS TO KEW 2 TOTALS

Year	0	1	2	3	4	5	6	7	8	9
169–								1.09	→	→
170–	→	→	→	→	→	→	→	→	→	→
171–	→	→	→	→	→	→	1.09	1.10	→	→
172–	→	→	→	→	1.10	1.11	→	→	→	→
173–	1.11	1.21	→	1.21	1.16	1.18	1	1	0.99	1.03
174–	0.93	1.05	1	→	→	→	→	→	→	→
175–	→	→	→	→	→	→	→	→	→	→
176–	→	→	→	→	1	1.07	→	→	→	→
177–	→	→	→	1.07	1.09	1.05	1.06	1.10	1.03	1.04
178–	1.07	1.07	1.05	1.08	1.03	1.08	1.08	1.09	1.11	1.06
179–	1.02	1.04	1.09	1.07	1.06	1.05	1	1.05	→	1.05
180–	1.06	1.03	1.07	1.03	→	→	1.03	1.10	1.09	1.06
181–	1.05	1.12	1.02	1.07	1.02	0.81	1.01	0.82	0.83	0.80
182–	0.81	0.96	0.88	0.95	0.94	0.96	0.95	0.91	0.89	1.07
183–	0.92	0.89	1.12	1.15	1.06	0.96	1.08	0.99	0.91	0.96
184–	1.17	0.95	1	1.06	0.94	1.06	1.12	0.96	0.98	0.99
185–	0.95	0.90	0.97	0.83	1.01	1.05	0.99	1.07	1.07	1.03
186–	0.90	0.92	1.07	1.01	1.03	0.92	0.87	0.80	1.05	0.94
187–	0.90									

4.4 John Hooker's records 1728–64

His diary (Royal Society MS NA188) shows that he lived in Kent throughout the period: at Falkham from 1728 to 1730, at North Fleet from 1731 to 1733 and at Tonbridge Castle (or very close by) from 1734 to 1764. In an attempt to separate the three records, archived as one continuous record for Tonbridge, 12-month running means were calculated for the period 1728–35 and the results expressed as percentages of the contemporary data for Crane Court. The percentages fell sharply from November 1730 and rose from November 1733. These changes were tentatively interpreted as indicating that 12-month totals extending through October 1730 and November 1733 each contained data from two records.

Annual values used to compare Falkham, North Fleet and Tonbridge with Crane Court had to be obtained by adding up 12-month rather than calendar year totals. Using the relationships obtained from these overlaps and accepting 1.10 as 'gauge and site' multiplying factor for Crane Court rainfall values, the factors for Hooker's three records are 1.08 for Falkham, 1.03 for North Fleet and 1.05 for Tonbridge. Professor Manley has estimated that Hooker's gauge at Tonbridge may have caught 90–95 per cent of the actual falls. The 1734–64 average of annual totals at Tonbridge is 27.06 in (687 mm); if this is multiplied by 1.05 (the factor obtained above) the result 28.52 in (724 mm) is surprisingly close to the modern average annual value 28.69 in (729 mm) and accordingly this factor has been accepted. When Kew 1 was compiled the whole of Hooker's combined record was known as Tonbridge. Refinements resulting from the studies described above have resulted in an increase in the values derived for 1728–35 for Kew and have, effectively, confirmed the earlier (Kew 1) estimates from 1736 to 1764.

4.5 Chelmsford 1738–41

Adopting 1.05 as the multiplying factor for Tonbridge implies a multiplying factor of 1.19 for Chelmsford. As nothing is known about the Chelmsford gauge and site and as no other comparison is available this factor has been accepted; it suggests significant under-catch. The Chelmsford record was not used in compiling Kew 1.

4.6 Lambeth 1765–82

In the period 1765–82 the Lambeth and estimated Pode Hole averages were, respectively, 106 per cent and 111 per cent of the corresponding modern averages. This would suggest that a multiplying factor 1.05 is required to adjust the Lambeth data. The only near records having overlaps with Lambeth are Crane Court 1774–79, Somerset House 1780 and South Lambeth 1782. If 1.05 is accepted as plausible for Lambeth (L) and since the overlap relationship with Crane Court (CC) is CC = 1.06 L this gives a multiplying factor 1.11 for Crane Court, almost the same as that already adopted. In Kew 1 the Lambeth data were accepted without modification.

4.7 Objective methods of processing overlapping records

4.7.1 *Tabulation, subdivision of records, quality control and selection*

Annual totals were tabulated against year date from 1697 onwards. A separate column was used for each station. Records from the same places but with sizeable gaps were annotated 1,2,3, etc. The records are shown, schematically, in Figure 1. Scatter diagrams of annual totals were plotted for all overlaps of 3 years or more and some double-mass analysis of annual totals was also carried out. From these processes the following conclusions were drawn:

(a) The Somerset House data may have been obtained from as many as 5 separate gauges and/or sites.

(b) The Greenwich Observatory data may have been obtained from as many as 4 separate gauges and/or sites.

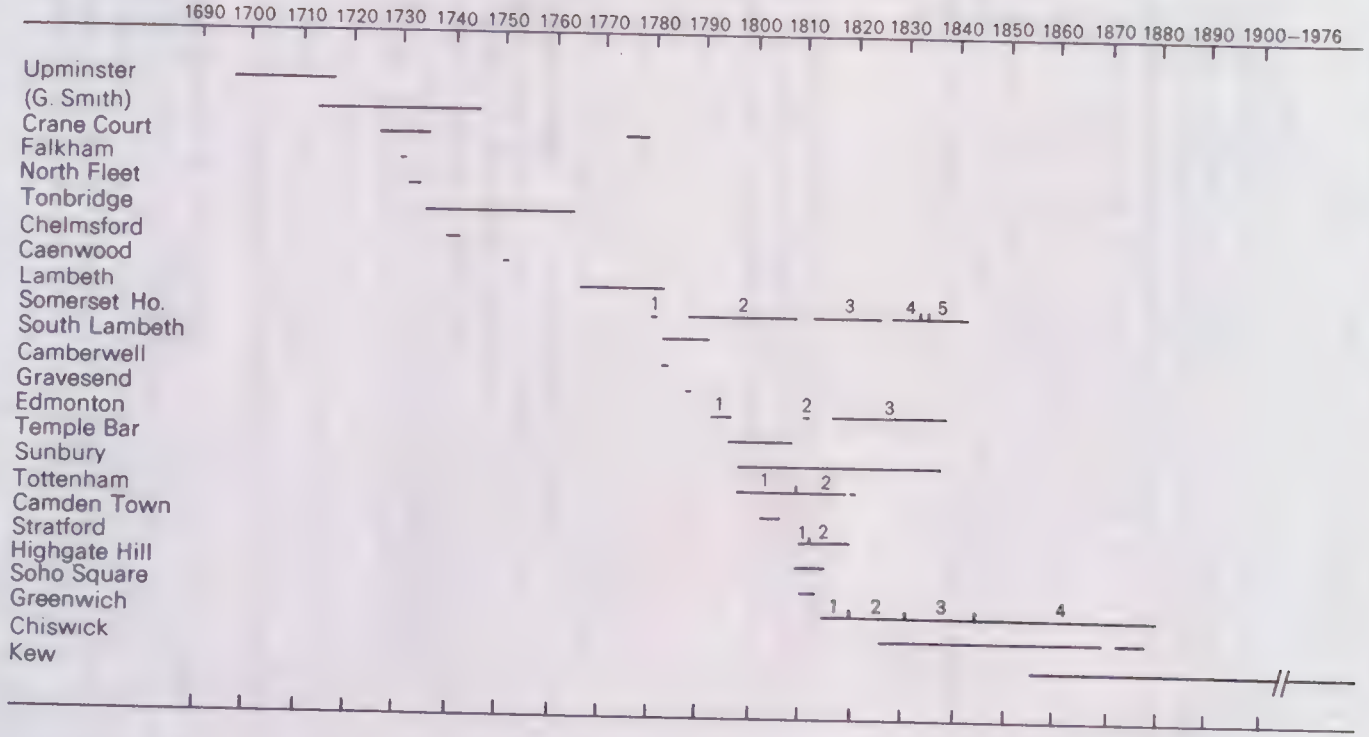

Figure 1. Periods covered by rainfall records studied in compiling Kew 2.

(c) The Somerset House 'sub-records' 3,4 and 5 (1812–42), the Camden Town record (1802–07) and the first Greenwich record (1815–20) appear to have been unreliable. In the compilation of Kew 1 the conclusion was drawn that the Somerset House record deteriorated after 1808.

From Figure 1 a link-diagram (Figure 2) was compiled, to show the chains of relationship used to adjust the early records to a 'good modern standard' *for their own sites*. The overlap between Kew and Chiswick is almost as long as that with Greenwich (used in compiling Kew 1). Chiswick is very close to Kew and, as can be seen from Figure 3, the annual totals for the 21-year overlap are satisfactorily close and therefore no use was made of Greenwich data for Kew 2.

4.7.2 *A simple equation for relating overlapping rainfall series*

Many workers have studied the relationships between rainfall totals measured, over various durations by gauges on the same site, on adjacent sites and at sites up to several tens of kilometres apart. For sites in Great Britain at similar altitudes above sea level and within, say, 50 km of one another, monthly totals are usually well related except for months in which one or two thunderstorms or heavy showers may provide the whole month's rainfall at a place. Monthly rainfall totals at Greenwich and Kew Observatories for the period 1856 to 1870 are compared in Figure 4. It can be seen that a reasonable estimate of the total at either station could usually have been made from that at the other. The totals reaching or exceeding 3.75 in (95.3 mm) in the months April to September are marked with the month number. It is probable that the largest differences usually resulted from convective phenomena affecting one station in a markedly different manner from the other. The two stations had almost exactly the same average annual rainfall for the periods 1881–1915 and 1916–50. The line of unit slope drawn in Figure 4 and the two, parallel lines at ± 0.5 in show how well most of the monthly totals agreed.

In order to make objective comparisons of annual totals at pairs of London area stations it was assumed that the mean relationship between annual or monthly totals at a pair of stations A and B could be expressed by the equation

$$\underline{\overline{A}}\,(\overline{B}b) = \underline{\overline{B}}\,(\overline{A}a) \qquad (1)$$

where $\underline{\overline{A}}$ and $\underline{\overline{B}}$ are modern annual averages, $\overline{A}$ and $\overline{B}$ are annual averages during the overlap of records, and a and b are gauge-and-site factors to adjust the A and B station data to good modern standard.

Since all except a and b are known for all comparisons equation (1) reduces to

$$b = Ka. \qquad (2)$$

The modern averages used in the comparison are given in the right-hand column of Table 2. A set of relationships of the form of equation (2) was obtained from all overlaps. The gauge-and-site factor for Kew was taken as 1.00 and other factors were obtained by successive substitutions.

4.7.3 *Test of variations in quality with time*

Tests to reveal possible deteriorations (or improvements) in records can be made by plotting cumulative yearly totals for one station against those for another (i.e. 1-year totals, 2-year totals ..... n-year totals). These comparisons were made for all overlaps of records, and the apparently poor records were identified by process of elimination.

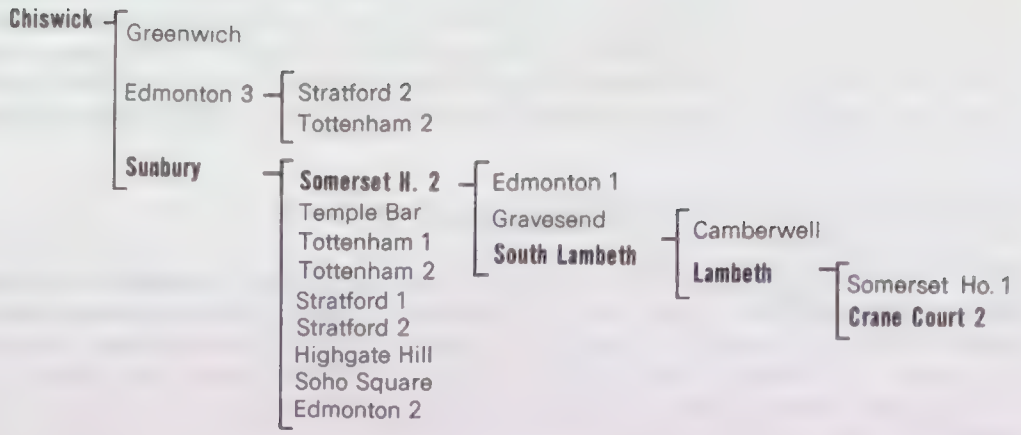

Figure 2. Records (other than Kew) used in compiling Kew 2 .

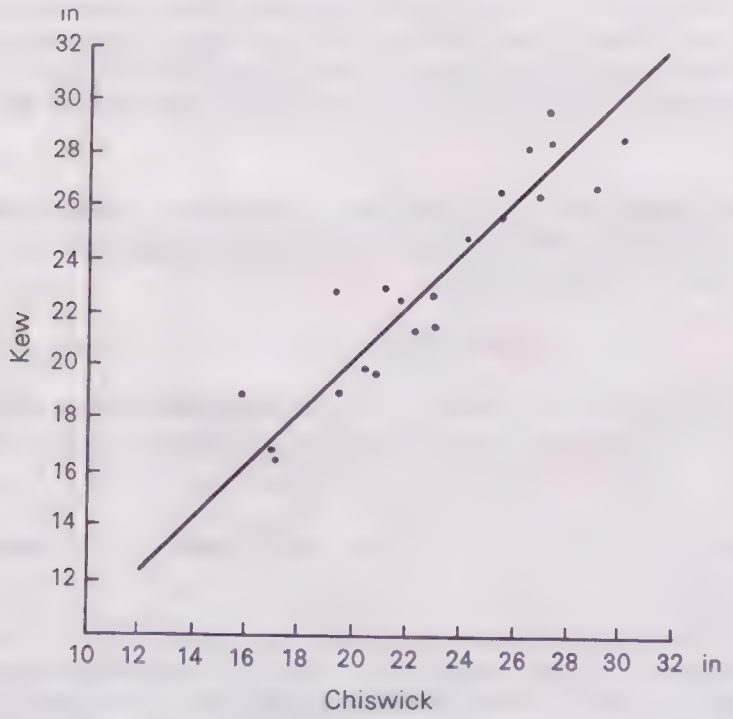

Figure 3. Scatter diagram of annual rainfall totals at Kew and Chiswick, 1856–70 and 1873–78.
Line : Kew = 1·018 Chiswick
21 year averages
Chiswick 22·98 in, Kew 23·39 in.

TABLE 2 – ASSUMED OR KNOWN POSITIONS OF SITES AND MODERN AVERAGE RAINFALLS

Station	Assumed or actual National Grid Ref.	1941–70 Average annual rainfall	
		in	mm
Upminster	TQ 560865	22.82	579.6
Crane Court	TQ 300810	23.75	603.3
Falkham	TQ600675	25.83	656.1
North Fleet	TQ 625747	22.23	564.6
Tonbridge	TQ 590450	28.69	728.7
Chelmsford	TQ 700070	22.79	578.9
Lambeth	TQ 306790	23.42	594.9
Somerset House	TQ 307808	23.78	604.0
South Lambeth	TQ 302770	23.60	599.4
Camberwell	TQ 340772	23.93	607.8
Gravesend	TQ 660710	24.47	621.5
Edmonton	TQ 340925	25.36	644.1
Temple Bar	TQ 305815	23.70	602.0
Sunbury	TQ 106685	23.75	603.3
Tottenham	TQ 336900	25.49	647.5
Camden Town	TQ 280850	25.39	644.9
Highgate Hill	TQ 283874	27.07	687.6
Stratford	TQ 389843	24.54	623.3
Soho Square	TQ 297812	24.17	613.9
Greenwich	TQ 392773	24.01	609.9
Chiswick	TQ 215777	23.88	606.5
Kew	TQ 171757	23.86	606.0

4.8 Processing the London area records

The above methods were used on all overlapping records and together with the deductions of 4.1 to 4.5 yielded (Kew 2) gauge-and-site factors which are compared with those used in compiling Kew 1.

Station	*Site*	*Kew 2 Factor*	*Kew 1 Factor*
Upminster	Roof	1.14	1.00
North Fleet	?	1.03	
Tonbridge	?	1.05	1.05
Falkham	?	1.08	
Chelmsford	?	1.19	
Crane Court	?	1.10	1.00
Lambeth	?	1.05	1.00
Somerset Ho. 1	Roof	1.18	
South Lambeth	?	1.07	1.00
Camberwell	?	1.05	
Gravesend	Ground	1.02	
Somerset Ho. 2	Roof	1.32	1.26
Edmonton 1	?	1.07	
Temple Bar	?	1.21	1.26
Sunbury	Ground	1.03	
Tottenham 1	Roof	1.12	
Tottenham 2	Ground	1.00	
Stratford 1	?	1.00	
Stratford 2	?	1.00	
Edmonton 2	?	1.00	
Highgate Hill	6 ft	1.00	
Soho Square	Roof	1.06	1.00
Edmonton 3	?	1.11	
Chiswick	Ground	1.02	
Kew	Ground	1.00	1.00

Because of the larger quantity of data and better methods used the Kew 2 factors are accepted in place of those obtained in compiling Kew 1.

4.9 Estimates of Kew rainfall from 1697–1855

Annual totals for all stations were adjusted using the factors listed in section 4.8. Each adjusted total was then multiplied by a factor formed from the averages in the right-hand column of Table 2 to give an estimate for Kew. Where two or more estimates were available they were averaged using a simple distance-weighting technique. It was judged best to obtain estimated monthly by adjusting those from the nearest of the stations used in any given year.

5. COMPARISONS BETWEEN KEW 1 AND KEW 2

Factors relating Kew 1 and Kew 2 annual totals are given in Table 1 and plotted in Figure 5. Decadal averages of the factors are given in Table 3 together with a count of numbers of cases in each decade in categories from 0.80 to 1.25.

5.1 Trends and important features

A brief commentary on some features of Kew 1 annual and seasonal totals was given in Wales-Smith (1973).

Figure 6 shows that decadal annual means were above the 270-year mean during the period 1761–1810 but that they fluctuated about the long-period mean over the rest of the series. The decadal median values follow the pattern of the decadal means. The sequence of decadal maxima shows no pronounced features. The highest value 969.5 mm (38.17 in) in 1903 considerably exceeds the rest. The distribution of minima within decades with time is also quite random; the driest years are 1731 and 1921. The decadal annual means of Kew 1 and Kew 2 are compared in Figure 7. The effects of the revision, including the introduction of many 'new' data, have been to make the early and later parts of the 18th century appear less dry and also to bring down the peak of high rainfall in the early 19th century. The 30-year running means of decadal means in Kew 2 oscillate randomly about the 270-year mean.

For summer (May–Aug.) Figure 7 shows the differences between the two series follow the pattern of the corresponding annual comparison. The decadal means and extremes of Figure 8 show no interesting trends. The wettest and driest summers occurred in 1903 and 1921 respectively, the years with the extreme maximum and minimum annual values.

The winter (Nov.–Feb.) patterns are also compared in Figure 7 and may be studied in detail in Figure 9. The decadal means are near or above the overall mean from the end of the 18th century and through the first three decades of the 19th century, remained near or below the long-period mean until the early 20th century and then returned above the mean until recently. The wettest winters became generally less wet from the mid-18th century to the mid-19th century since when they have generally become wetter again. The driest winters tended to become drier from the mid-18th century until the beginning of the present century. Spring data (Mar.–Apr.) are displayed in Figure 7 and in Figure 10. The diagrams show little of interest, apart from the early run of wetter than average decadal values and the two, later runs of drier than average decadal values. Autumn data (Sept.–Oct.) are displayed in Figure 7 and in Figure 11. Generally dry autumns were typical of the early 18th century and have been experienced again during the present century. This season was generally wetter during the intervening period. There have been signs of a trend towards less wet maxima and drier minima this century.

5.2 Frequency analysis

It has been shown that Kew 2 is generally wetter than Kew 1 from 1697 to 1735 and from 1765 to 1814 and variously wetter and drier thereafter. This section compares the characteristics of the two series which are, of course, identical from 1871 to 1970.

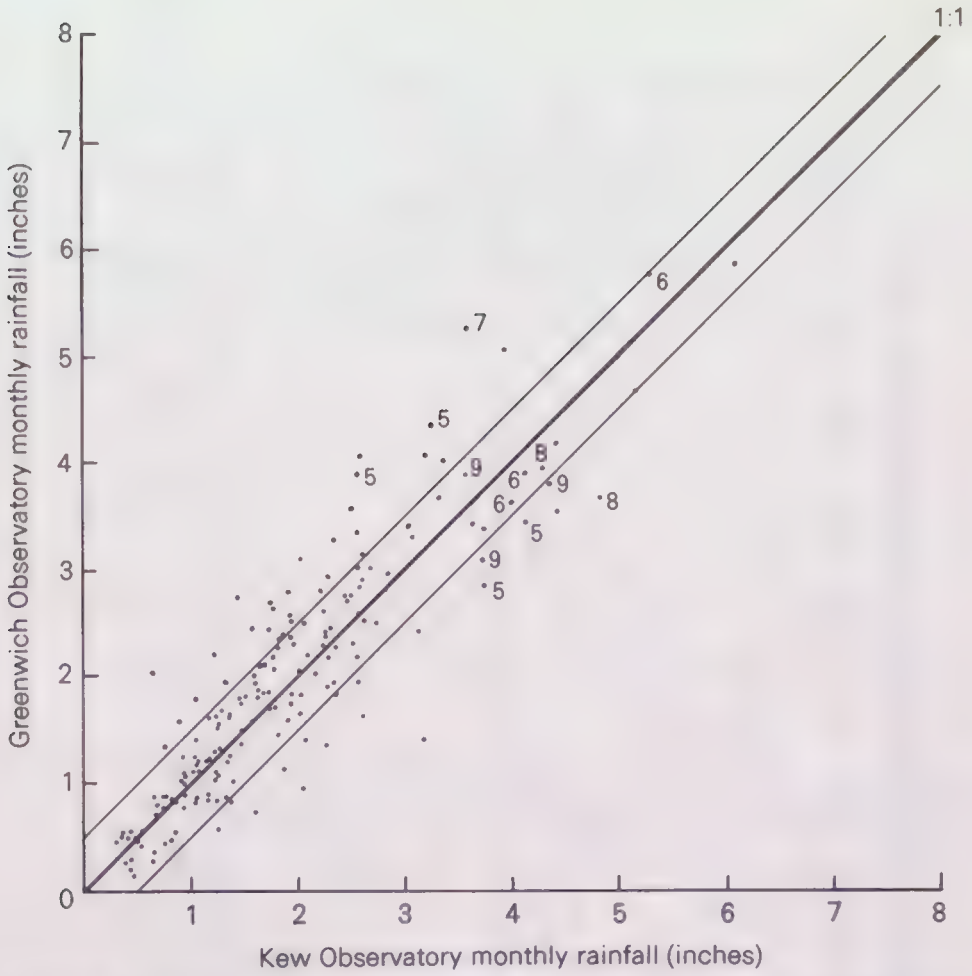

Figure 4. Scatter diagram of monthly rainfall totals at Kew and Greenwich 1856–70. Totals ≥ 3·75 in (95·3 mm) in the months April–September are marked with month numbers.

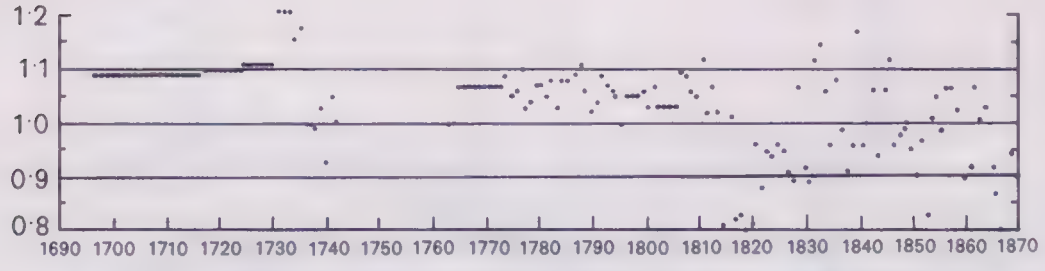

Figure 5. Multiplying factors relating Kew 1 annual rainfall totals to those in Kew 2, 1697–1870.

TABLE 3 – NUMBERS OF CASES OF KEW 1 TO KEW 2 FACTOR WITHIN GIVEN LIMITS FOR EACH DECADE

	1701	1711	1721	1731	1741	1751	1761	1771	1781	1791	1801	1811	1821	1831	1841	1851	1861
1.21–1.25					3												
1.16–1.20					2									1			
1.11–1.15				6					1			1		2	1		
1.06–1.10		10	10	4			6	7	6	4	4	1	1	2	2	2	1
1.01–1.05					1	1		3	3	5	6	3				3	3
1					2	9	10	4		1					1		
0.99–0.95					1								4	3	5	2	
0.94–0.90					1								3	1	1	2	4
0.89–0.85													2	1			1
0.84–0.80												5				1	1
0.79–0.75																	
Decadal averages	1.09	1.09	1.11	1.09	1.00	1.00	1.04	1.07	1.07	1.05	1.05	0.93	0.94	1.03	1.00	0.98	0.95

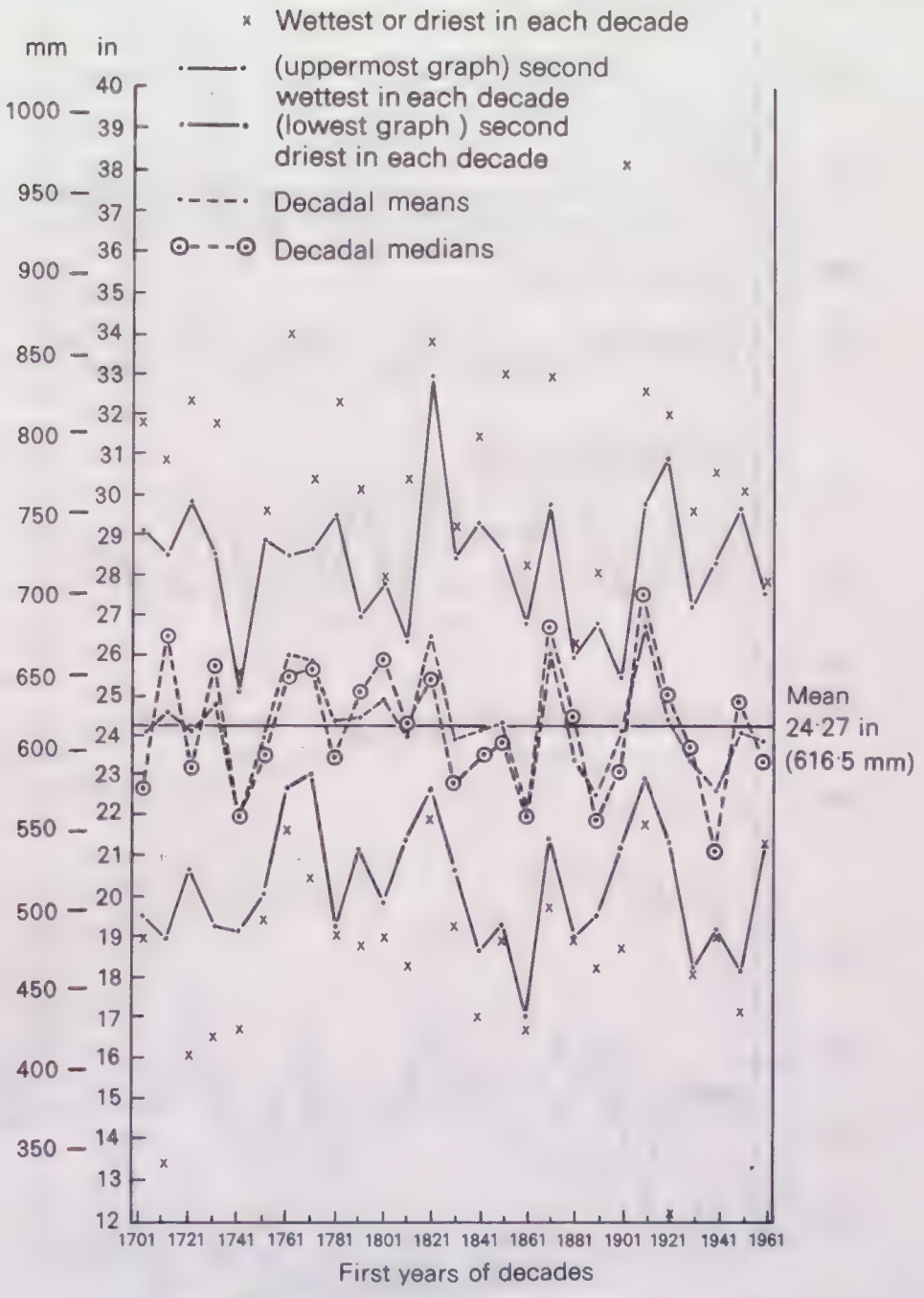

Figure 6. Annual rainfall representative of Kew.

Note. In this and subsequent diagrams many data are plotted, for convenience, against the first year of the decade.

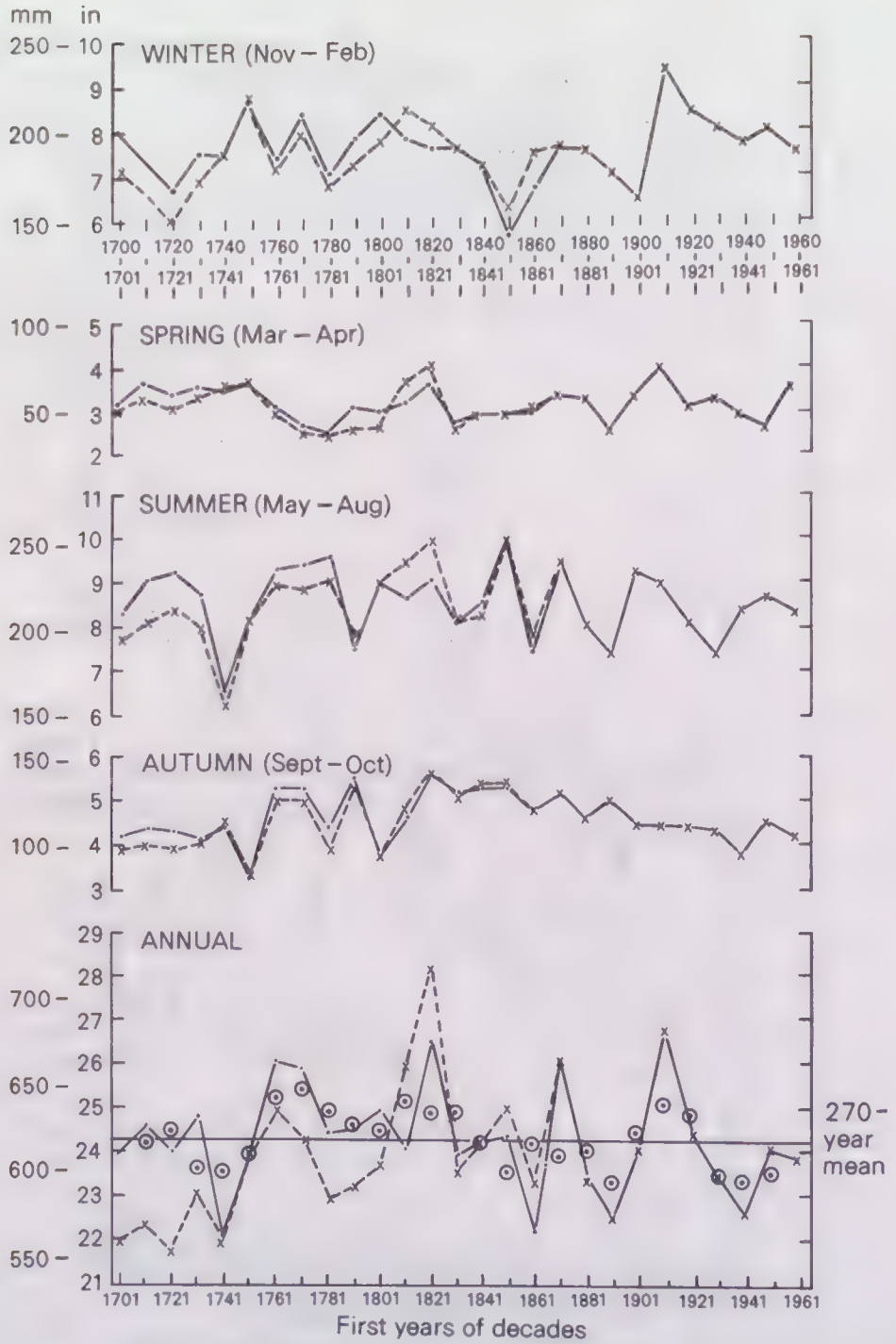

Figure 7. Annual and seasonal rainfall totals of Kew 1 and Kew 2.

×– – –× Decadal means (Kew 1) ·—— · Decadal means (Kew 2)

⊙ 30-year running means of Kew 2 decadal means

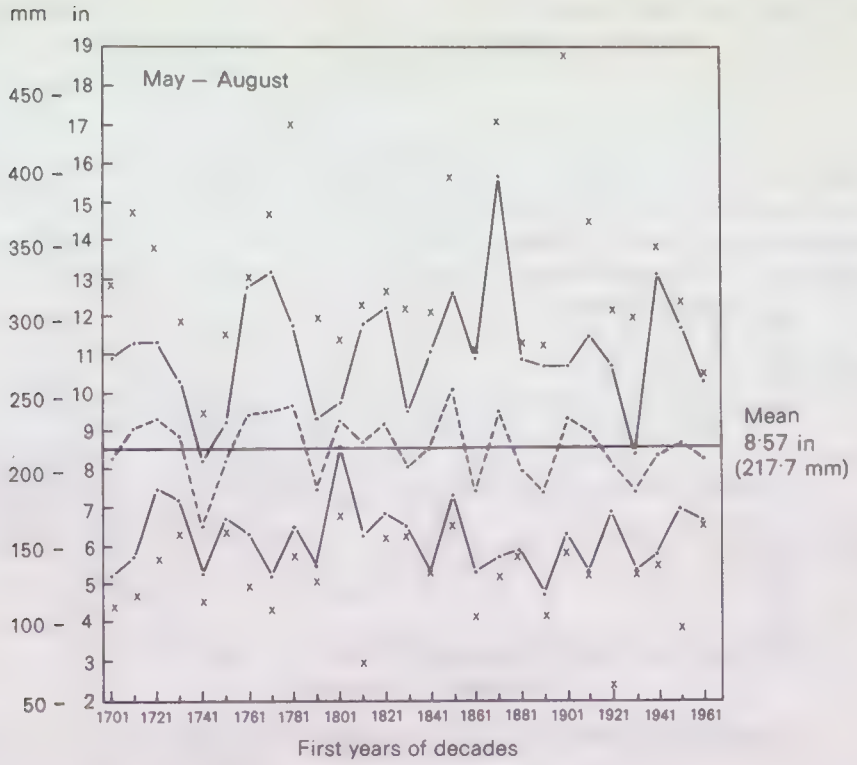

Figure 8. Summer rainfall representative of Kew
(Symbols as Figure 6)

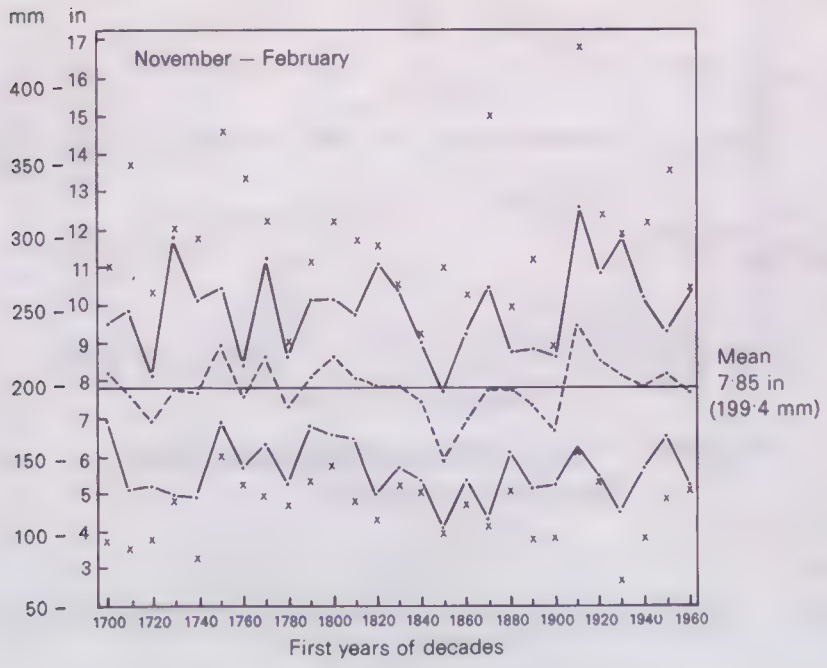

Figure 9. Winter rainfall representative of Kew
(Symbols as Figure 6)

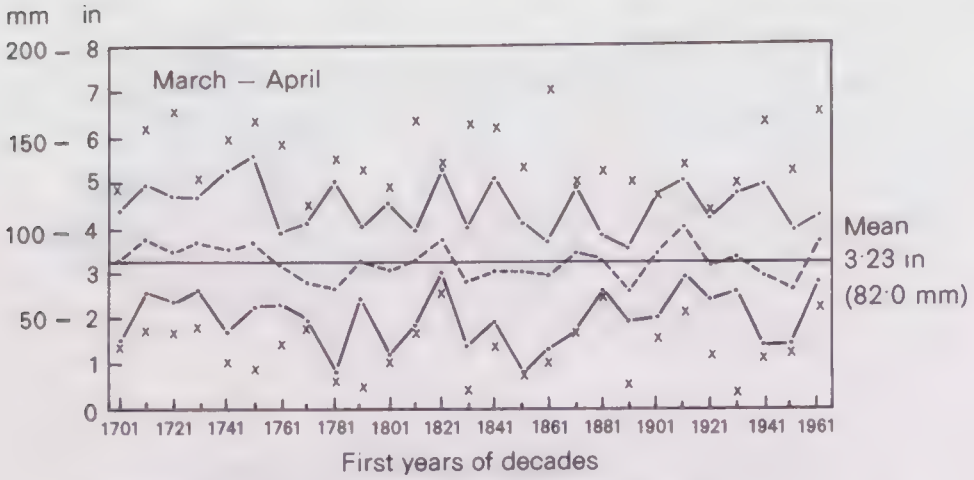

Figure 10. Spring rainfall representative of Kew
(Symbols as Figure 6)

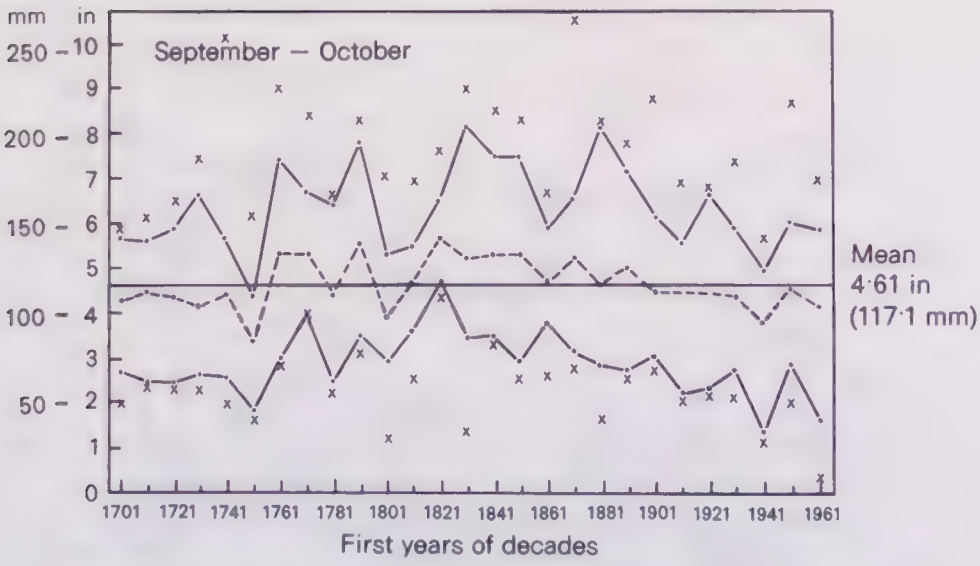

Figure 11. Autumn rainfall representative of Kew
(Symbols as Figure 6)

Figure 12, showing frequencies of occurrence of seasonal and annual totals is the revised version of Figure 1 in Wales-Smith (1973). Figure 13 shows the differences between the two sets of diagrams. The main feature is a slight shift towards higher values.

Tables 4 and 5 are the revised versions of Tables II and III in Wales-Smith (1973). They include 6 additional years (1971–76) and also an additional statistic, the change in mm (+/–) from the event of corresponding rank in Kew 1. The changes in the rainfalls of the top 6 and bottom 6 ranks for single, named months and for named groups of 2 to 6 months are predominantly upwards but they are generally small in amount.

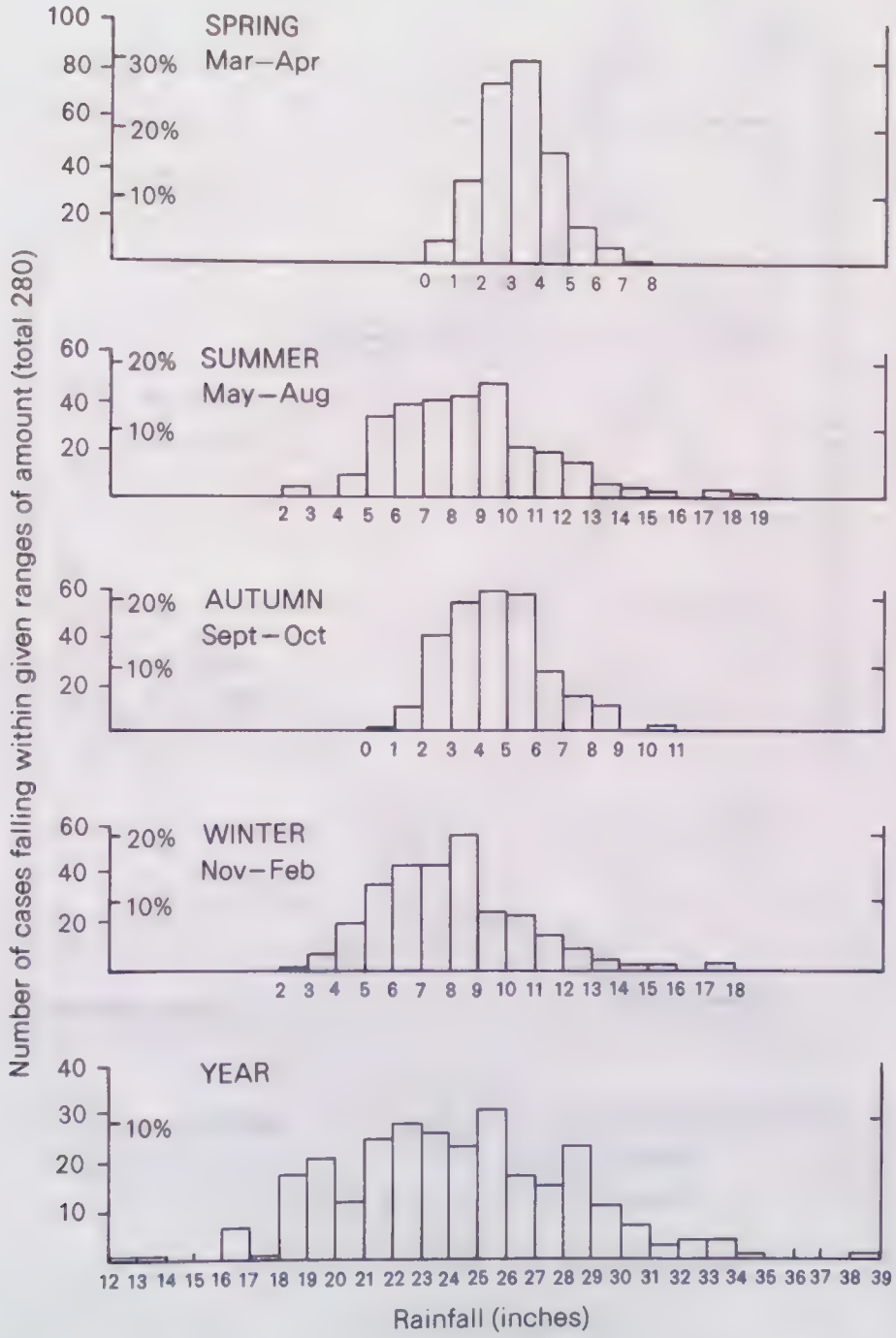

Figure 12. Frequency diagrams of seasonal and annual totals of rainfall representative of Kew 1697-1976.

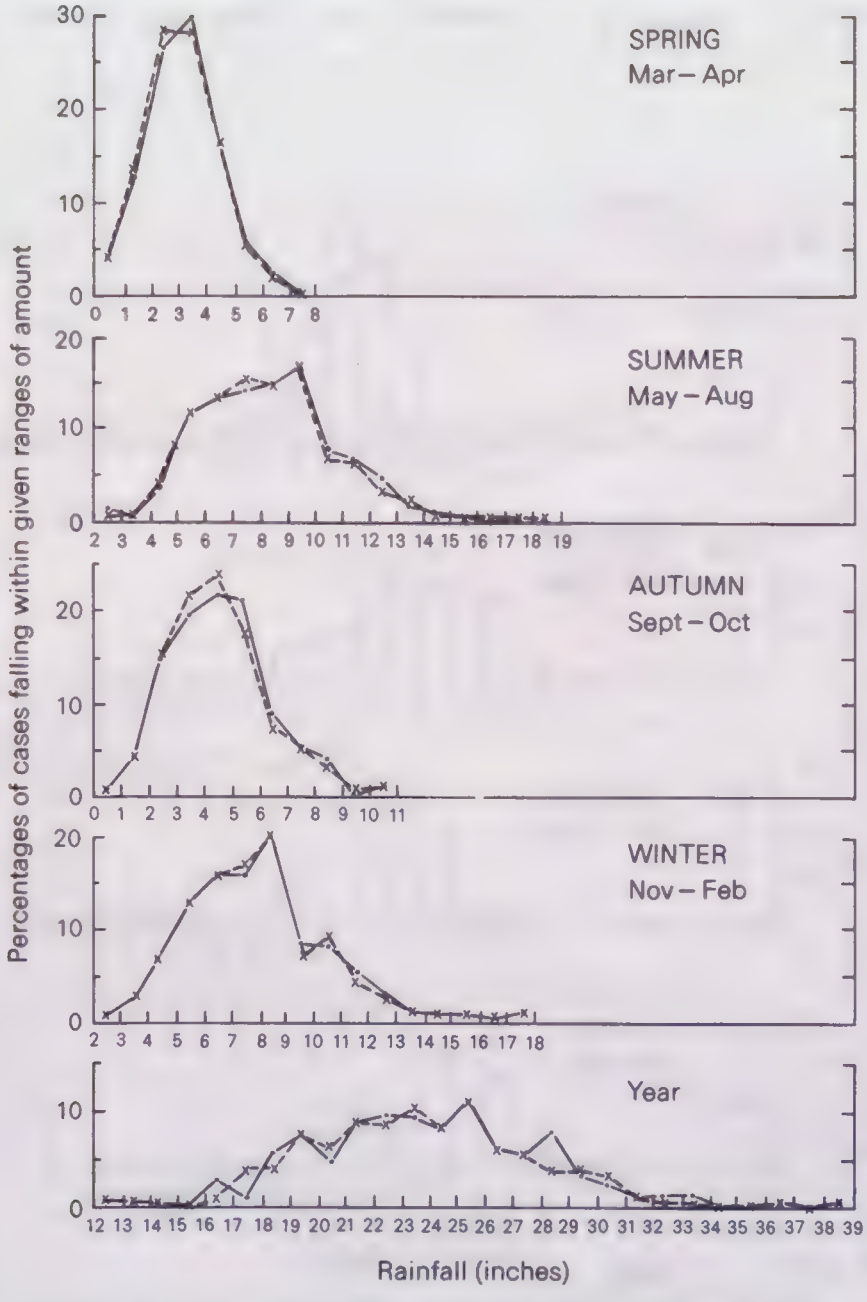

Figure 13. Comparison of frequencies of seasonal and annual rainfall totals of Kew 1 (×---×) and Kew 2 (•——•). Note. For example 7–8 means 7·01–8·00 in.

TABLE 4(a) — SIX WETTEST OF EACH MONTH AT KEW 1697–1976

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Wettest						
Amount (mm)	136.7	126.5	118.4	118.1	140.0	183.1	184.1	165.6	147.3	169.9	189.0	169.4
Year	1749	1951	1947	1829	1777	1903	1782	1878	1775	1744	1755	1747
Change	0	0	0	(-3.8)	(-0.7)	0	(+6.3)	0	(+2.3)	0	0	0
Amount (mm)	127.5	120.4	113.5	111.8	136.1	135.9	178.1	149.6	145.0	159.3	171.7	166.6
Year	1877	1763	1862	1744	1843	1860	1779	1941	1918	1855	1940	1914
Change	0	0	(+10.6)	0	(+19.3)	(-11.4)	(+3.6)	0	(+5.5)	(+8.2)	0	0
Amount (mm)	120.1	105.7	100.8	101.9	126.0	131.3	164.3	134.4	144.8	156.2	160.5	146.6
Year	1943	1776	1730	1846	1703	1971	1834	1912	1768	1865	1852	1876
Change	0	(+1.3)	(+0.5)	(+3.6)	(+10.4)	(-4.3)	(-0.8)	0	(+8.2)	(+5.1)	(+3.5)	0
Amount (mm)	117.6	104.4	100.3	98.3	123.4	129.3	163.1	132.6	140.5	151.1	157.0	140.7
Year	1764	1879	1916	1878	1734	1728	1855	1737	1797	1880	1970	1779
Change	0	(+1.5)	(+0.2)	(+0.8)	(+12.4)	(-0.2)	(+5.9)	0	(+5.1)	(+0.5)	(+2.6)	(+3.8)
Amount (mm)	116.1	103.1	100.1	97.5	110.5	124.2	150.6	128.3	138.9	150.6	156.2	136.9
Year	1713	1833	1914	1756	178.2	1768	1956	1879	1726	1891	1810	1915
Change	(+6.6)	(+0.7)	(+1.0)	(+2.0)	(+3.8)	(+7.1)	0	0	(+8.3)	(+0.7)	(+3.8)	(+1.8)
Amount (mm)	112.3	102.9	97.5	97.3	107.9	121.4	143.0	124.2	136.1	147.1	138.2	132.3
Year	1809	1937	1704	1728	1727	1852	1766	1715	1896	1882	1974	1705
Change	(+3.1)	(+8.9)	(+1.0)	(+4.3)	(+2.0)	(+4.6)	(+3.8)	(+1.0)	(+9.1)	0	(+3.8)	(+0.2)

TABLE 4(b) — SIX DRIEST OF EACH MONTH AT KEW 1967–1976

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						Driest						
Amount (mm)	2.5	2.3	0.8	1.5	4.8	1.0	0.0	0.5	1.8	2.8	6.9	0.0
Year	1855	1959	1929	1840	1896	1925	1800	1730	1754	1788	1749	1788
Change	(+0.6)	(+2.3)	0	(-0.8)	0	0	0	0	(+1.8)	(+0.8)	0	0
Amount (mm)	3.0	2.3	2.3	1.5	5.6	5.1	2.8	2.0	2.5	3.8	7.4	2.8
Year	1740	1891	1944	1817	1956	1921	1825	1727	1959	1947	1945	1762
Change	(+0.3)	0	(+1.0)	(-0.8)	(+0.5)	0	(+0.3)	(+0.2)	(+0.7)	0	0	(+0.3)
Amount (mm)	3.3	2.8	2.3	2.3	6.3	6.3	3.8	2.3	2.8	4.1	9.7	3.8
Year	1766	1725	1796	1938	1844	1923	1921	1940	1969	1969	1858	1829
Change	(-1.5)	(+0.5)	(+0.3)	0	(+0.7)	0	0	(+0.3)	(+0.3)	0	(-0.2)	(+1.0)
Amount (mm)	6.3	3.3	2.3	2.5	7.4	6.3	10.2	2.3	3.0	5.1	9.9	6.1
Year	1779	1895	1781	1893	1880	1757	1955	1726	1795	1809	1956	1926
Change	(+0.2)	(+0.8)	0	0	0	0	(+3.3)	0	(+0.5)	(+0.5)	(-0.3)	0
Amount (mm)	6.6	4.3	2.5	3.8	7.4	6.6	10.9	2.5	3.3	6.9	11.2	6.6
Year	1705	1932	1742	1912	1848	1932	1835	1742	1743	1708	1727	1835
Change	(+0.3)	(+1.0)	(+0.2)	(+1.3)	(-0.2)	0	(+3.3)	0	(+0.5)	(+0.6)	(+0.5)	(-1.5)
Amount (mm)	6.9	4.3	2.8	3.8	8.4	6.6	11.4	2.8	4.1	8.6	11.9	7.9
Year	1838	1790	1768	1842	1895	1794	1794	1818	1929	1781	1901	1853
Change	(+0.3)	0	(+0.3)	0	0	(-0.5)	(+1.2)	(+0.3)	(+0.8)	(+0.5)	(+1.0)	(-1.2)

Values in brackets are differences in millimetres from first six ranks in Kew 1

TABLE 5(a) — SIX WETTEST SETS OF 1 TO 6 CONSECUTIVE MONTHS STARTING IN APRIL AND OCTOBER AT KEW, 1697–1976

	Apr.	Apr.–May	Apr.–June	Apr.–July	Apr.–Aug.	Apr.–Sept.	Oct.	Oct.–Nov.	Oct.–Dec.	Oct.–Jan.	Oct.–Feb.	Oct.–Mar.
						Wettest						
Amount (mm)	118.1	202.4	312.9	421.4	521.2	603.2	169.9	260.6	347.7	379.5	463.0	483.4
Year	1829	1878	1903	1903	1903	1903	1744	1852	1821	1876	1914	1914
Change	(-3.8)	0	0	0	0	0	0	(+12.9)	(+30.2)	0	0	0
Amount (mm)	111.8	202.2	290.8	401.3	512.8	579.6	159.3	237.2	311.7	379.0	423.9	479.8
Year	1744	1703	1703	1728	1879	1879	1855	1939	1852	1914	1876	1876
Change	0	(+17.0)	(+17.2)	(+16.7)	0	0	(+8.2)	(-7.9)	(+2.8)	0	(-4.6)	0
Amount (mm)	101.9	178.1	273.6	384.6	497.6	557.3	156.2	232.9	308.9	373.4	417.6	476.8
Year	1846	1843	1879	1879	1878	1782	1865	1940	1755	1929	1712	1755
Change	(+3.6)	(+0.8)	(+1.3)	(+21.1)	0	(+29.5)	(+5.1)	(-4.3)	(+2.8)	0	(+6.3)	0
Amount (mm)	98.3	177.3	272.3	381.8	494.3	553.5	151.1	229.1	305.3	367.0	412.5	466.9
Year	1878	1879	1878	1703	1782	1768	1880	1755	1779	1852	1755	1911
Change	(+0.8)	(+9.4)	(+0.5)	(+24.4)	(+24.4)	(+31.0)	(+0.5)	(-3.8)	(+0.8)	(+2.0)	0	(-3.0)
Amount (mm)	97.5	171.4	272.0	376.2	454.2	535.7	150.6	228.6	304.5	365.0	406.1	455.9
Year	1756	1782	1728	1782	1715	1829	1891	1960	1929	1755	1738	1915
Change	(+2.0)	(+8.6)	(+5.8)	(+26.9)	(+9.7)	(+18.3)	(+0.7)	(-0.5)	(+1.0)	(+1.5)	(+5.3)	(-11.0)
Amount (mm)	97.3	168.1	262.1	371.9	448.3	522.5	147.1	217.2	285.2	363.5	400.8	454.4
Year	1728	1732	1777	1777	1728	1878	1882	1794	1810	1911	1882	1940
Change	(+4.3)	(+5.5)	(+5.6)	(+29.0)	(+11.9)	(+7.4)	0	(-11.4)	(-4.9)	(+6.4)	(+3.0)	(-1.5)

TABLE 5(b) — SIX DRIEST SETS OF 1 TO 6 CONSECUTIVE MONTHS STARTING IN APRIL AND OCTOBER AT KEW, 1697–1976

	Apr.	Apr.–May	Apr.–June	Apr.–July	Apr.–Aug.	Apr.–Sept.	Oct.	Oct.–Nov.	Oct.–Dec.	Oct.–Jan.	Oct.–Feb.	Oct.–Mar.
						Driest						
Amount (mm)	1.5	15.0	40.1	60.7	82.5	130.6	2.8	19.8	19.8	74.7	104.6	140.7
Year	1840	1844	1844	1921	1976	1921	1788	1788	1788	1879	1933	1724
Change	(-0.8)	(-1.5)	(+11.1)	0	(-3.4)	0	(+0.8)	(+2.0)	(+2.0)	0	0	(+12.9)
Amount (mm)	1.5	19.3	44.2	61.7	85.9	142.7	3.8	31.0	63.5	75.4	118.4	147.8
Year	1817	1762	1938	1870	1921	1972	1947	1947	1879	1788	1714	1879
Change	(-0.8)	(+0.2)	0	(-8.4)	(-45.4)	(-8.9)	0	(+0.8)	0	(-3.6)	(+10.2)	0
Amount (mm)	2.3	19.6	44.4	69.1	113.0	147.8	4.1	33.0	68.6	95.0	122.2	155.7
Year	1938	1896	1976	1976	1870	1870	1969	1708	1933	1834	1890	1890
Change	0	(+0.3)	(-11.7)	(-10.9)	(-20.9)	(-13.2)	0	(+2.0)	(+1.8)	(+6.1)	(+4.1)	0
Amount (mm)	2.5	25.9	45.2	70.1	114.6	151.6	5.1	37.3	73.2	99.1	129.8	158.2
Year	1893	1795	1870	1938	1972	1959	1809	1897	1714	1933	1931	1975
Change	0	(+6.3)	(-11.7)	(-12.4)	(-20.5)	(-21.1)	(+0.5)	(+1.0)	(+4.6)	(+8.2)	(+7.6)	(-0.3)
Amount (mm)	3.8	29.7	56.9	82.5	133.9	174.5	6.9	40.9	73.7	99.6	130.0	158.5
Year	1912	1956	1921	1762	1896	1893	1708	1752	1891	1714	1724	1933
Change	(+1.3)	(+4.8)	(-0.5)	(-4.1)	(-4.8)	(+1.8)	(+0.6)	(+3.6)	(+2.6)	(+0.5)	(+0.2)	(-4.1)
Amount (mm)	3.8	31.0	58.2	92.5	138.7	175.8	8.6	41.1	75.9	111.3	130.3	159.8
Year	1842	1870	1895	1781	1938	1705	1781	1919	1834	1809	1879	1828
Change	0	(+1.8)	0	(+3.1)	(-2.5)	(+1.3)	(+0.5)	(+1.5)	(+2.2)	(-1.5)	0	(-6.1)

Values in brackets are differences in millimetres from first six ranks in Kew 1

The results of re-analysis using the 'new' sets of extreme values are shown in Tables 6 and 7. It can be seen that the changes for single months are all small. The changes for sets of 2 to 6 consecutive months are also mostly small. There is some evidence that the 50-year and 100-year April–Sept. and Apr.–July totals in Figure 4 of Wales-Smith (1973) should be increased by about the amounts shown in the table; also that the 100-year dry Apr.–July, Apr.–Aug. and Apr.–Sept. events in Figure 5 of Wales-Smith (1973) may be slightly too large. Examination of Tables 6 and 7 suggests no good reasons for altering the relationships between rainfall and return period suggested in Figure 6 of Wales-Smith (1973).

TABLE 6(a) — APPROXIMATE CHANGES (KEW 1 TO KEW 2) IN MONTHLY TOTALS WHICH ARE REACHED OR EXCEEDED IN 1 IN 5 TO 1 IN 100 YEARS

	Return period									
	5 years		10 years		20 years		50 years		100 years	
	mm	per cent	mm	per cent	mm	per cent	mm	per cent	mm	per cent
Jan.	+0.5	0.7	+2.8	3.3	+0.8	0.8	+4.3	3.8	−0.6	0.5
Feb.	0	0	+1.2	1.7	+3.3	3.9	+4.7	4.6	+0.1	0.1
Mar.	+2.0	3.5	+1.5	2.1	−1.1	1.3	+0.8	0.8	−2.0	1.9
Apr.	+1.6	2.6	−0.8	1.1	−1.5	1.9	+3.2	3.3	+1.9	1.8
May.	0	0	+1.8	2.2	+0.8	0.8	+2.6	2.4	+12.2	9.5
June	+5.9	7.6	+1.5	1.6	+2.5	2.4	+0.6	0.5	−6.5	4.9
July	−5.3	6.3	−0.3	0.2	−1.5	1.2	+1.0	0.7	−0.5	0.3
Aug.	+0.7	0.9	−2.5	2.6	+0.6	0.5	+0.1	0.1	−1.0	0.7
Sept.	+1.5	1.9	+2.8	2.8	+3.3	2.9	+8.5	6.2	+7.9	5.5
Oct.	−1.3	1.5	−3.3	3.2	−3.8	3.0	−0.1	0.1	+4.4	2.8
Nov.	+4.9	5.7	−0.3	0.3	+0.8	0.7	+1.6	1.1	+2.0	1.2
Dec.	−0.5	0.4	−2.0	2.2	+1.8	1.6	+0.6	0.5	+2.0	1.3
Mean	+0.8		+0.2		+0.5		+2.3		+1.6	

Percentages refer to Kew 2 threshold values

TABLE 6(b) — APPROXIMATE CHANGES (KEW 1 TO KEW 2) IN MONTHLY TOTALS WHICH WERE NOT EXCEEDED WITH GIVEN RETURN PERIODS

	Return period				
	5 years	10 years	20 years	50 years	100 years
	mm	mm	mm	mm	mm
Jan.	−0.3	−0.5	+1.0	+0.5	−1.0
Feb.	−0.2	−1.2	−0.2	+1.0	+1.2
Mar.	0	+0.2	+0.2	+0.4	+1.0
Apr.	+1.0	+0.5	0	0	−0.2
May.	−0.5	+1.0	+1.0	+0.1	+0.9
June	+0.8	+0.5	−2.3	−0.3	+1.8
July	0	+0.8	+2.8	+3.3	0
Aug.	+1.5	0	+0.7	−2.6	−0.3
Sept.	0	−1.0	+1.0	−1.3	+0.4
Oct.	−0.5	−1.5	−0.2	+0.8	−0.1
Nov.	+0.5	+1.0	+1.0	+0.9	+0.1
Dec.	+1.6	+0.2	−0.2	+1.6	+0.8
Mean	+0.3	0	+0.4	+0.4	+0.4

TABLE 7(a) — APPROXIMATE CHANGES (KEW 1 TO KEW 2) IN THE *n*-MONTHLY TOTALS WHICH ARE REACHED OR EXCEEDED IN 1 IN 5 TO 1 IN 100 YEARS

	Return period									
	5 years		10 years		20 years		50 years		100 years	
	mm	per cent	mm	per cent	mm	per cent	mm	per cent	mm	per cent
Oct.	−1.3	1.5	−3.3	3.2	−3.8	3.0	+3.7	2.5	+4.4	2.8
Oct.–Nov.	+3.3	2.1	+5.6	3.1	+4.0	1.9	−7.2	3.3	−5.5	2.3
Oct.–Dec.	+2.2	1.0	+0.3	0.1	−0.3	0.1	−4.4	0.1	+2.6	0.1
Oct.–Jan.	+9.0	3.3	+2.8	0.9	−1.8	0.5	+3.7	1.0	+3.8	1.0
Oct.–Feb.	+6.3	2.0	+10.2	2.9	+8.7	2.3	+3.8	0.9	−6.3	1.5
Oct.–Mar.	+2.1	0.6	+5.1	1.3	+0.1	0	−6.8	1.5	−0.1	0
Apr.	+1.6	2.6	−0.8	1.1	−1.5	1.9	+3.2	3.3	+1.9	1.8
Apr.–May	−1.0	0.9	−0.3	0.2	+1.5	1.0	+6.7	3.9	+3.6	1.0
Apr.–June	+5.1	2.8	+1.0	0.5	−0.8	0.4	+4.5	1.7	+2.2	0.8
Apr.–July	+5.1	2.1	−0.5	0.2	−5.3	1.7	+27.4	7.3	+18.8	4.9
Apr.–Aug.	+5.6	1.8	+2.8	0.8	−0.2	0.1	+1.0	0.2	−1.1	0.2
Apr.–Sept.	+6.1	1.6	+0.8	0.2	+2.0	0.4	+11.4	2.2	+11.8	2.1

Percentages refer to Kew 2 threshold values

TABLE 7(b) — APPROXIMATE CHANGES (KEW 1 TO KEW 2) IN THE *n*-MONTHLY TOTALS WHICH WERE NOT EXCEEDED WITH GIVEN RETURN PERIODS

	Return period				
	5 years	10 years	20 years	50 years	100 years
	mm	mm	mm	mm	mm
Oct.	−0.5	−1.5	−0.2	+0.8	−0.1
Oct.–Nov.	+0.5	+1.5	+2.6	+2.7	+1.9
Oct.–Dec.	+1.8	+2.8	+3.3	+2.6	+1.8
Oct.–Jan.	+1.5	+5.3	+4.2	+0.9	−2.3
Oct.–Feb.	+3.7	+3.9	−2.1	−2.4	+1.0
Oct.–Mar.	+7.1	+7.1	+0.7	−5.9	+2.9
Apr.	+1.0	+0.5	0	0	−0.2
Apr.–May	+0.3	+1.8	+0.3	+3.6	−2.6
Apr.–June	0	+2.3	−1.0	0	−8.7
Apr.–July	−0.2	+1.8	+4.9	+0.6	−9.9
Apr.–Aug.	−4.6	+1.3	+1.8	+1.2	−16.9
Apr.–Sept.	+3.8	−3.3	−2.3	+1.8	−11.7

6. CONCLUSIONS

The author has tried to seek out records and 'station' details, but has not been able to visit all the sites and carry out local searches for more information. It is almost certain that some readers will be able to add to the body of information presented here. Perhaps, in due course, Kew 3 will be compiled, using, if possible real data in place of estimates for 1717-24. If daily data can be found for the period 1697–1752 it will be possible to adjust the early part of the assemblage to the new-style calendar (introduced in September 1752) a task urged upon the author by Professor Manley but one which he has, so far, been unable to undertake.

It can be said, with confidence, that Kew 2 is a better assemblage than Kew 1. The major improvement is the use of good-quality records from Kew, itself, or nearby from 1797 onwards. The second improvement arises from the use of additional records and station details for 1697-1796, allowing a more scientific approach to be employed.

It is satisfactory, however, that although the revision invalidates some of the general comments made in the analysis of Kew 1, the results of the rainfall frequency analyses have required only a few, fairly minor, amendments.

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APPENDIX

MONTHLY AND ANNUAL TOTALS OF RAINFALL OBSERVED AT OR ESTIMATED FOR KEW FOR THE PERIOD 1697–1870 (KEW 2)

Note: Apportioning *n*-month rainfall totals to individual months

The methods used in compiling Kew 1 were adopted to subdivide *n*-month (including annual) totals where no other information was available.

A single asterisk against a year-date indicates that all monthly totals were apportioned. Single asterisks against members of sets of consecutive months indicates apportionment within those sets. Double asterisks against months in 1785 and 1786 indicate apportionment by reference to the records for Lyndon, Selborne and Andover.

	1697	1698	1699	1700
January	0.86	2.62	2.13	0.94
February	0.43	0.31	1.45	1.84
March	0.65	2.24	1.35	0.37
April	1.80	1.93	0.82	1.83
May	0.77	2.89	0.65	1.66
June	1.18	2.10	1.05	1.83
July	1.48	4.09	1.59	1.02
August	3.35	1.68	2.06	1.95
September	2.50	2.90	1.93	3.54
October	2.01	3.14	3.22	4.10
November	1.35	4.03	0.47	1.26
December	2.23	1.41	1.40	2.47
Totals	18.61	29.34	18.12	22.81

	1701	1702	1703	1704	1705	1706*	1707	1708	1709*	1710*	
January	3.58	2.35	2.13	0.97	0.26	2.59	1.13*	3.43	2.83	1.96	
February	2.11	1.75	1.54	0.53	1.32	1.86	0.65*	0.55	2.03	1.41	
March	0.94	0.57	1.14	3.84	1.33	1.77	0.59*	2.42	1.95	1.35	
April	0.35	2.61	3.00	1.13	1.23	2.21	0.87*	1.15	2.41	1.67	
May	2.19	1.55	4.96	0.53	0.49	2.21	1.26	2.41	2.41	1.67	
June	1.39	3.25	3.49	1.58	0.79	2.10	1.60	2.77	2.29	1.59	
July	2.27	1.05	3.58	1.54	1.33	2.97	1.52	1.32	3.26	2.24	
August	1.57	1.65	0.81	0.75	2.59	2.71	2.60	3.52	2.96	2.04	
September	1.35	1.93	3.57	1.78	0.49	2.42	3.45	1.74	2.65	1.83	
October	2.45	1.89	2.29	0.97	3.85	2.73	1.57	0.27	2.99	2.07	
November	1.97	3.36	1.74	2.14	1.40	3.05	1.41	1.03	3.32	2.30	
December	2.24	2.47	0.51	3.18	5.21	2.50	2.90	2.34	2.73	1.89	
Totals and decadal mean	22.41	24.43	28.76	18.94	20.29	29.12	19.55	22.95	31.83	22.02	24.03

	1711*	1712*	1713*	1714*	1715	1716	1717*	1718*	1719*	1720*	
January	2.51	2.54	4.57	0.42	1.04	2.07	0.99	1.98	0.88	0.44	
February	1.81	1.83	3.81	1.26	0.74	0.41	1.54	0.99	1.65	2.97	
March	1.73	1.74	0.75	1.43	3.01	0.47	2.86	1.98	1.98	2.09	
April	2.15	2.17	1.84	1.36	3.16	1.20	2.09	2.09	1.21	2.09	
May	2.15	2.17	2.27	0.67	1.13	2.27	1.43	1.76	1.32	2.42	
June	2.03	2.06	3.05	1.18	3.91	1.98	1.76	1.98	2.09	1.87	
July	2.89	2.91	4.31	1.50	4.79	1.07	2.20	1.32	0.99	4.40	
August	2.63	2.65	1.53	1.36	4.89	0.50	2.31	0.66	3.18	2.63	
September	2.35	2.36	0.61	1.36	2.20	2.36	2.20	1.76	1.10	2.09	
October	2.66	2.67	1.84	1.11	3.38	3.80	2.20	2.97	1.87	3.30	
November	2.95	2.94	1.53	0.84	2.05	1.06	4.39	4.06	2.20	2.20	
December	2.44	2.45	1.66	0.93	0.61	1.72	1.21	3.30	0.99	1.87	
Totals and decadal mean	28.30	28.49	27.77	13.42	30.91	18.91	25.18	24.85	19.46	28.37	24.57

	1721*	1722*	1723*	1724*	1725	1726	1727	1728	1729	1730	
January	1.65	0.66	1.21	3.29	0.72	4.33	2.66	3.41	0.82	0.50	
February	0.99	0.88	1.98	1.10	0.11	0.71	2.28	0.70	0.87	1.36	
March	1.10	2.20	0.55	1.98	0.42	1.61	2.32	2.75	1.25	3.97	
April	3.30	1.10	1.10	1.10	2.18	0.75	0.59	3.83	1.77	0.74	
May	1.43	1.98	0.88	1.32	3.05	1.97	4.25	1.79	1.67	1.93	
June	3.08	1.54	1.10	2.20	4.48	3.75	3.15	5.09	1.33	4.15	
July	1.87	4.39	3.29	3.30	0.83	4.63	0.88	5.09	1.15	2.64	
August	1.76	2.53	0.33	2.42	2.98	0.09	0.08	1.85	3.36	0.02	
September	3.08	0.44	0.88	2.09	2.94	5.47	1.93	1.86	3.87	2.32	
October	2.75	1.98	1.43	1.32	1.36	1.08	1.90	2.53	1.57	2.72	
November	3.84	1.98	1.32	1.43	1.29	1.45	0.44	2.39	2.69	1.73	
December	1.21	0.99	1.98	1.54	1.82	3.99	2.84	1.11	2.15	1.66	
Totals and decadel mean	26.06	20.67	16.05	23.09	22.18	29.83	23.32	32.40	22.50	23.74	23.98

	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740	
January	0.50	0.66	0.83	1.17	2.78	3.54	0.57	1.60	3.80	0.12	
February	1.09	2.58	1.40	2.24	2.09	2.58	2.84	0.99	4.04	0.30	
March	0.21	1.46	2.60	2.08	2.64	2.07	3.08	2.72	1.50	0.93	
April	1.54	2.49	2.06	0.52	1.37	0.67	1.01	1.81	3.60	2.12	
May	0.38	4.13	0.67	4.86	2.40	1.38	1.63	1.36	2.42	1.21	
June	2.87	1.14	3.21	3.73	2.45	2.72	1.57	3.65	1.90	1.03	
July	2.35	1.65	1.86	1.29	3.69	1.30	0.93	1.23	2.64	1.53	
August	1.58	1.49	3.91	2.05	1.75	1.90	5.22	2.10	2.53	2.56	
September	0.66	1.20	1.66	1.16	1.84	1.44	4.57	2.69	3.32	1.89	
October	1.59	3.52	1.10	2.44	1.15	3.14	2.88	3.95	0.73	0.71	
November	1.67	1.52	0.63	2.06	3.17	0.95	0.86	2.27	3.21	3.04	
December	2.03	1.96	2.95	4.97	1.77	3.48	1.40	1.93	2.07	3.82	
Totals and decadal mean	16.47	23.80	22.88	28.57	27.10	25.17	26.56	26.30	31.76	19.26	24.79

	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750	
January	0.92	2.51	0.81	0.51	0.58	2.48	2.47	0.56	5.38	2.54	
February	1.16	1.31	0.78	1.60	0.54	2.38	2.42	1.07	1.30	2.31	
March	0.49	0.10	1.82	1.55	2.82	1.93	1.17	2.49	1.75	1.05	
April	0.55	1.54	2.15	4.40	2.42	1.41	1.13	2.51	1.44	2.72	
May	3.21	1.50	1.04	0.53	1.06	1.67	0.60	0.91	1.09	1.39	
June	1.83	2.08	0.89	1.71	4.21	3.72	3.60	2.25	1.48	1.19	
July	1.77	1.96	2.82	0.94	1.35	1.86	1.30	0.92	1.09	2.04	
August	1.38	0.10	1.69	2.02	2.81	0.81	0.35	1.74	0.80	0.85	
September	2.87	2.43	0.13	3.42	1.17	1.68	2.48	1.04	2.21	1.77	
October	2.76	2.09	1.82	6.69	3.14	1.71	0.74	1.51	2.32	2.07	
November	2.37	2.79	1.14	1.67	2.69	1.60	1.84	0.59	0.27	3.34	
December	1.21	0.67	1.63	0.53	2.29	1.86	6.67	4.56	1.71	2.84	
Totals and decadal mean	20.52	19.08	16.72	25.57	25.08	23.11	24.77	20.15	20.84	24.11	21.99

	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760	
January	2.93	1.95	2.19	2.30	1.12	2.21	2.79	1.76	1.45	2.19	
February	1.40	2.01	1.89	1.49	0.69	1.87	0.91	2.30	0.69	2.90	
March	3.45	1.23	1.30	2.04	1.30	2.53	1.64	1.58	2.36	0.56	
April	2.15	0.99	2.30	1.07	2.71	3.84	2.69	1.09	1.60	0.26	
May	2.33	1.79	1.51	1.19	1.87	0.49	1.21	1.22	1.11	1.19	
June	1.66	2.19	0.81	2.09	1.80	2.42	0.25	1.90	2.92	2.51	
July	3.71	2.35	1.41	1.45	2.20	2.11	1.78	5.11	0.98	1.99	
August	1.53	1.52	2.55	2.81	3.07	3.85	3.54	3.35	1.72	2.29	
September	2.64	1.26	0.60	0.07	2.00	1.20	1.23	1.18	1.32	2.89	
October	1.65	0.37	1.20	2.23	1.58	3.12	1.49	1.44	2.67	3.21	
November	4.08	1.24	2.44	2.66	7.44	1.31	2.14	2.29	1.16	1.47	
December	2.08	2.51	2.35	4.32	3.14	1.93	2.11	1.60	1.95	1.95	
Totals and decadal mean	29.61	19.41	20.55	23.72	28.92	26.88	21.78	24.82	19.93	23.41	23.90

	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770	
January	0.32	2.46	0.29	4.63	2.42	0.13	2.23	1.79	1.82	1.03	
February	1.52	1.30	4.74	1.95	1.84	2.43	2.88	2.29	1.83	1.21	
March	0.70	2.05	1.38	0.98	3.57	2.47	1.96	0.11	0.90	1.60	
April	0.70	0.27	1.16	1.74	2.28	1.41	1.51	3.38	1.51	2.29	
May	3.10	0.49	0.98	1.40	1.35	3.49	2.87	1.12	2.23	1.59	
June	2.58	1.66	1.27	1.19	0.99	2.99	2.43	4.89	3.58	4.33	
July	0.66	0.83	3.06	2.75	0.51	5.63	4.07	2.73	1.94	1.81	
August	3.27	3.35	2.16	3.29	2.03	0.82	3.44	3.97	2.36	1.01	
September	2.82	1.86	2.30	1.30	1.19	0.47	1.79	5.70	5.03	2.68	
October	2.64	5.54	1.61	1.62	4.65	2.39	2.30	3.27	1.25	2.39	
November	1.92	1.68	2.90	1.75	2.20	1.06	1.41	2.45	1.65	5.02	
December	2.45	0.11	3.98	2.39	0.93	1.74	0.53	2.35	2.07	3.53	
Totals and decadal mean	22.68	21.60	25.83	24.99	23.96	25.13	27.42	34.05	26.17	28.49	26.03

	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780	
January	1.91	3.46	1.45	3.09	1.94	1.39	1.10	2.40	0.25	0.81	
February	0.87	3.34	1.52	2.74	2.32	4.16	1.54	0.66	0.28	0.93	
March	0.98	2.03	0.25	2.22	2.16	1.65	1.51	1.45	0.57	1.46	
April	1.06	2.04	1.50	1.25	1.07	0.36	1.02	0.85	1.39	3.02	
May	1.40	1.61	3.88	1.96	0.86	1.76	5.51	1.25	2.11	1.02	
June	2.73	0.72	3.05	1.95	1.42	2.11	3.79	1.26	2.82	1.04	
July	1.57	0.78	1.36	2.50	5.00	2.10	4.32	4.23	7.01	1.63	
August	4.51	2.07	4.24	3.57	1.82	2.72	1.11	0.67	1.26	0.63	
September	1.29	2.56	2.92	4.07	5.80	3.17	0.67	0.81	2.66	3.40	
October	3.27	2.52	1.98	1.38	2.60	0.78	3.71	3.09	3.28	3.25	
November	0.81	2.94	4.59	1.87	2.45	2.15	1.07	4.15	3.20	2.87	
December	2.73	1.12	1.96	1.99	0.70	1.52	0.86	2.95	5.54	0.40	
Totals and decadal mean	23.13	25.19	28.70	28.59	28.14	23.87	26.21	23.77	30.37	20.46	25.84

	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790	
January	2.09	2.79	1.63	3.01	1.92	2.67	0.57	0.65	2.19	1.44	
February	2.07	0.58	3.21	1.58	1.29	1.17	1.61	2.09	2.42	0.17	
March	0.09	2.84	1.00	2.80	0.38	1.20	1.73	0.58	2.28	0.20	
April	0.48	2.40	0.64	2.72	0.37	1.32	1.11	0.65	1.30	2.33	
May	0.77	4.35	2.55	1.45	0.87	1.05	1.63	0.77	2.23	3.94	
June	1.24	0.81	4.31	3.68	2.20	2.42	0.81	3.17	4.14	0.83	
July	1.15	7.25	0.84	1.95	1.87	0.93	4.39	2.05	3.14	2.43	
August	3.38	4.65	2.40	2.44	3.28	1.28	1.10	4.11	2.27	2.55	
September	2.09	2.48	4.64	1.75	2.97	2.38**	1.07	4.26	2.44	0.53	
October	0.34	2.16	0.78	0.88	2.90**	4.00**	2.54	0.11	4.07	1.66	
November	3.67	1.11	1.76	3.35	1.46**	2.47**	1.71	0.67	1.49	3.52	
December	1.65	0.97	1.31	2.38	1.65	3.30	4.08	0	1.60	3.09	
Totals and decadal mean	19.02	32.39	25.07	27.99	21.16	24.19	22.35	19.11	29.57	22.69	24.35

	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800	
January	2.86	2.68	2.04	0.67	0.66	2.71	1.91	1.97	2.27	3.83	
February	1.79	0.77	1.95	0.88	1.67	1.46	0.22	0.51	2.44	0.31	
March	0.97	2.42	2.01	1.61	2.32	0.09	1.57	0.83	1.03	1.15	
April	1.83	2.89	1.28	1.88	0.65	0.39	2.45	1.59	2.47	2.80	
May	0.94	2.17	1.08	2.57	0.37	2.83	2.17	1.49	2.16	2.02	
June	0.53	2.07	0.67	0.26	4.44	0.69	3.56	1.25	0.34	1.20	
July	2.90	2.35	1.93	0.45	1.85	2.42	2.54	3.66	2.70	0	
August	1.23	2.71	1.73	1.73	2.46	0.68	3.65	1.93	2.86	2.57	
September	0.47	2.99	3.13	4.34	0.12	1.96	5.53	3.17	4.20	2.90	
October	2.61	2.82	1.36	3.89	3.37	2.30	2.25	3.86	2.90	1.26	
November	3.54	0.60	3.15	4.66	3.23	1.55	1.99	4.20	1.89	4.42	
December	1.52	2.50	2.75	1.92	1.29	1.67	2.36	1.28	0.86	2.94	
Totals and decadal mean	21.19	26.97	23.08	24.86	22.43	18.75	30.20	25.74	26.12	25.40	24.47

	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	
January	1.42	0.52	1.82	2.49	2.46	2.35	0.73	1.29	4.42	0.40	
February	0.88	1.73	1.02	1.46	1.24	1.17	1.29	0.91	2.12	1.61	
March	1.58	0.43	0.69	2.75	1.19	2.18	0.67	0.41	1.23	2.72	
April	0.59	0.75	1.64	1.80	2.39	1.28	0.44	2.35	3.68	1.73	
May	2.52	1.96	1.86	1.86	1.29	1.09	2.94	1.64	0.46	0.95	
June	0.90	2.69	4.54	0.41	3.66	0.77	0.97	1.52	1.46	0.84	
July	4.47	2.06	0.96	4.07	3.72	5.56	0.85	3.23	4.51	3.69	
August	1.64	2.14	1.24	3.24	2.71	1.51	1.93	3.34	2.74	3.25	
September	1.99	0.67	0.66	0.38	2.02	2.25	2.99	3.21	3.23	1.59	
October	1.64	2.22	0.52	3.35	2.26	1.26	2.33	3.79	0.20	2.09	
November	4.01	1.59	3.90	4.60	1.10	3.61	3.79	2.47	1.67	6.15	
December	3.26	2.17	4.50	0.91	2.44	3.76	0.86	1.21	2.11	2.99	
Totals and decadal mean	24.90	18.93	23.35	27.32	26.48	26.79	19.79	25.37	27.83	28.01	24.88

	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	
January	1.13	1.62	0.74	2.54	0.88	2.53	3.12	2.25	2.09	1.89	
February	1.62	3.76	3.15	0.33	0.81	1.63	0.86	1.81	2.19	0.89	
March	0.59	2.17	0.81	1.35	1.98	1.72	2.23	3.25	1.22	0.27	
April	1.27	1.64	1.49	1.98	1.23	2.21	0.06	3.16	2.43	1.42	
May	3.39	2.83	2.40	2.62	1.52	2.31	3.65	1.85	2.87	2.57	
June	2.17	3.03	1.27	2.31	1.66	2.88	1.13	0.42	1.96	2.31	
July	4.09	2.17	2.15	2.32	1.39	4.03	3.00	0.53	1.39	2.73	
August	2.14	1.35	0.99	2.05	1.62	2.91	2.82	0.11	1.46	2.33	
September	1.49	0.64	1.70	1.26	1.23	1.97	1.17	2.58	3.76	3.11	
October	3.33	4.41	5.16	2.40	2.97	2.45	1.36	1.33	1.71	2.31	
November	2.45	2.30	1.24	2.43	1.32	2.34	1.25	2.63	1.85	1.17	
December	1.81	0.46	0.69	3.45	1.66	3.48	3.10	1.52	1.90	1.53	
Totals and decadal mean	25.48	26.38	21.79	25.04	18.27	30.46	23.75	21.44	24.83	22.53	24.00

	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830	
January	2.25	0.38	1.74	1.14	0.97	0.27	0.76	3.74	0.31	1.59	
February	0.21	1.01	3.17	2.83	0.91	1.72	0.80	0.95	1.11	1.35	
March	2.74	1.49	1.24	1.74	1.04	1.63	2.54	0.59	0.77	0.19	
April	2.55	3.07	1.92	1.90	2.33	0.89	0.72	2.46	4.65	2.92	
May	1.74	1.59	1.21	3.59	2.71	2.40	2.28	1.41	0.54	2.54	
June	2.07	0.60	1.39	3.11	0.88	0.38	0.83	1.95	2.45	2.70	
July	2.84	2.95	3.00	1.91	0.11	2.08	1.33	4.42	5.41	1.50	
August	2.55	1.44	2.56	3.62	3.24	2.01	1.69	4.38	4.21	3.14	
September	2.39	1.22	1.88	3.33	2.79	3.74	3.44	4.06	3.83	3.30	
October	3.45	4.29	2.80	3.13	2.65	2.15	4.14	1.19	1.65	1.01	
November	5.07	4.14	1.59	4.16	3.48	2.91	1.08	1.13	1.92	3.14	
December	5.17	2.15	3.31	3.53	2.60	1.78	3.14	1.78	0.15	1.59	
Totals and decadal mean	33.03	24.33	25.81	33.99	23.71	21.96	22.75	28.06	27.00	24.97	26.56

	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840	
January	1.03	1.32	0.53	2.93	0.75	2.05	3.16	0.27	1.29	2.53	
February	2.30	0.23	4.06	0.38	2.71	1.64	2.09	2.22	2.23	1.27	
March	1.93	1.50	1.25	0.88	2.04	3.36	0.56	0.86	1.71	0.29	
April	1.99	0.95	2.77	0.66	1.10	2.93	1.17	0.52	1.49	0.06	
May	2.24	2.16	0.69	1.22	3.50	1.03	1.11	0.92	0.83	2.22	
June	1.39	2.89	2.68	1.67	2.06	1.69	1.36	3.65	3.05	1.51	
July	2.55	0.89	1.59	6.47	0.43	1.81	1.85	2.19	2.97	1.71	
August	1.61	3.62	1.97	2.79	0.19	2.01	3.17	1.23	1.88	1.65	
September	4.26	1.12	1.58	0.85	4.76	3.87	0.95	2.08	3.99	2.50	
October	3.86	3.09	2.42	0.44	4.20	3.68	2.49	2.36	2.27	1.38	
November	1.72	1.94	2.43	1.79	2.01	3.67	1.37	3.55	4.35	3.66	
December	2.41	1.88	4.38	0.76	0.26	1.51	1.40	1.72	2.36	0.46	
Totals and decadal mean	27.29	21.59	26.35	20.84	24.01	29.25	20.68	21.57	28.42	19.24	23.92

	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850	
January	2.65	1.08	1.35	2.29	3.03	2.90	1.33	1.18	1.76	1.46	
February	0.77	1.35	2.39	2.31	0.95	1.50	1.37	3.18	2.57	0.97	
March	1.35	1.84	0.48	2.49	1.27	1.11	0.42	3.11	0.87	0.13	
April	1.61	0.15	1.65	0.34	0.97	4.01	0.94	3.12	2.25	1.82	
May	2.20	1.76	5.36	0.25	2.94	1.38	1.62	0.29	3.60	1.87	
June	2.50	1.61	1.65	0.99	1.39	0.81	1.33	3.26	0.32	1.43	
July	3.36	1.55	1.70	2.14	2.35	1.81	0.81	2.25	2.87	2.73	
August	2.74	2.86	3.34	1.87	2.84	4.59	1.53	4.79	1.63	0.99	
September	3.78	3.45	1.00	1.33	1.80	1.79	1.69	2.24	2.54	2.41	
October	4.70	1.74	4.27	4.21	1.42	5.65	1.78	2.99	2.22	1.58	
November	3.47	4.51	2.17	3.12	2.15	1.46	2.30	0.92	1.35	2.07	
December	2.16	0.77	0.59	0.40	2.66	1.23	1.85	2.07	1.30	1.17	
Totals and decadal mean	31.56	22.67	25.95	21.74	23.77	28.24	16.97	29.40	23.28	18.63	24.22

	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860	
January	3.13	2.77	2.18	1.96	0.10	1.79	2.58	0.96	0.69	2.36	
February	0.92	1.08	0.60	0.79	1.37	1.06	0.42	1.80	1.34	1.03	
March	3.64	0.25	1.51	0.43	1.78	0.95	1.22	1.39	1.47	1.66	
April	1.68	0.53	2.63	0.31	0.27	2.22	2.09	2.37	2.57	1.40	
May	0.75	1.77	1.63	4.11	1.98	4.19	0.66	2.17	1.85	2.56	
June	1.35	4.78	2.59	1.56	1.51	0.89	1.75	1.15	3.19	5.35	
July	3.97	2.32	4.25	2.45	6.42	1.18	1.25	2.60	2.35	2.82	
August	2.07	3.78	1.91	1.80	1.48	3.15	2.78	1.47	1.98	4.89	
September	0.43	3.61	2.45	0.59	1.17	1.92	3.79	1.07	4.39	2.02	
October	2.05	3.94	3.85	2.66	6.27	2.56	4.46	1.84	2.53	1.22	
November	0.56	6.32	0.93	1.33	1.37	1.05	1.47	0.38	2.60	1.96	
December	0.63	2.01	0.31	1.29	1.13	1.95	0.34	1.73	1.77	1.45	
Totals and decadal mean	21.18	33.16	24.84	19.28	24.85	22.91	22.81	18.93	26.73	28.72	24.34

	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870	
January	0.46	1.64	2.49	0.96	3.10	3.43	2.21	3.35	2.30	1.23	
February	1.51	0.41	0.51	0.73	1.95	3.39	1.25	1.08	1.94	1.27	
March	2.30	4.47	0.68	2.63	0.81	1.23	1.98	0.95	1.06	1.78	
April	1.08	2.58	0.30	0.86	0.45	1.72	1.69	1.48	1.26	0.40	
May	1.06	3.77	1.39	1.59	3.27	1.32	1.22	0.77	3.06	0.82	
June	2.29	2.37	4.17	2.06	1.58	4.02	1.36	0.43	1.04	0.56	
July	2.10	2.05	0.76	0.67	1.82	1.20	3.61	1.62	0.88	0.65	
August	0.59	2.69	1.75	1.25	4.34	2.31	2.06	2.52	1.17	2.02	
September	1.83	2.60	2.82	2.50	0.47	3.59	2.26	2.24	3.75	1.37	
October	0.75	3.22	2.04	1.28	6.15	1.63	1.62	2.27	1.44	2.57	
November	3.96	0.91	1.92	1.93	1.86	1.27	0.78	0.92	2.27	1.36	
December	0.93	1.58	1.12	0.49	0.65	1.70	1.29	5.20	2.46	2.61	
Totals and decadal mean	18.86	28.29	19.95	16.95	26.45	26.81	21.33	22.83	22.63	16.64	22.07